Severe weather on the intraseasonal time scale

Bradford S. Barrett

Oceanography Department, U.S. Naval Academy

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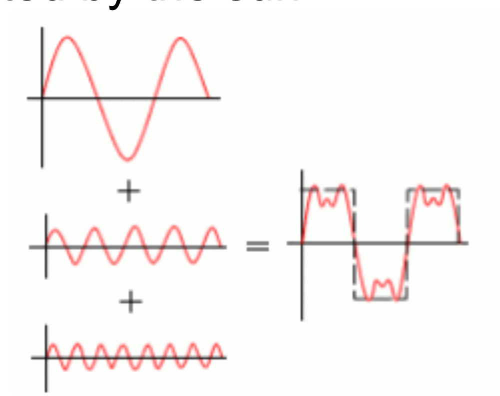
Atmospheric oscillations

- The weather we notice here in College Park today is really the combination of many atmospheric oscillations
  - Diurnal, synoptic-scale (passage of fronts, for example), intraseasonal, seasonal, interannual (El Niño, for example)
- Owing to the superposition principle, sometimes these oscillations combine with the same sign (“constructive interference”), other times with the opposite sign (“destructive interference”)
  - Example: a cold front passes during a clear afternoon. The “cold air” doesn’t seem so cold because it’s heated by the sun

Simple example of superposition:

- El Niño/La Niña (top curve)
- Front passages (middle curve)
- Day-night cycle (bottom curve)



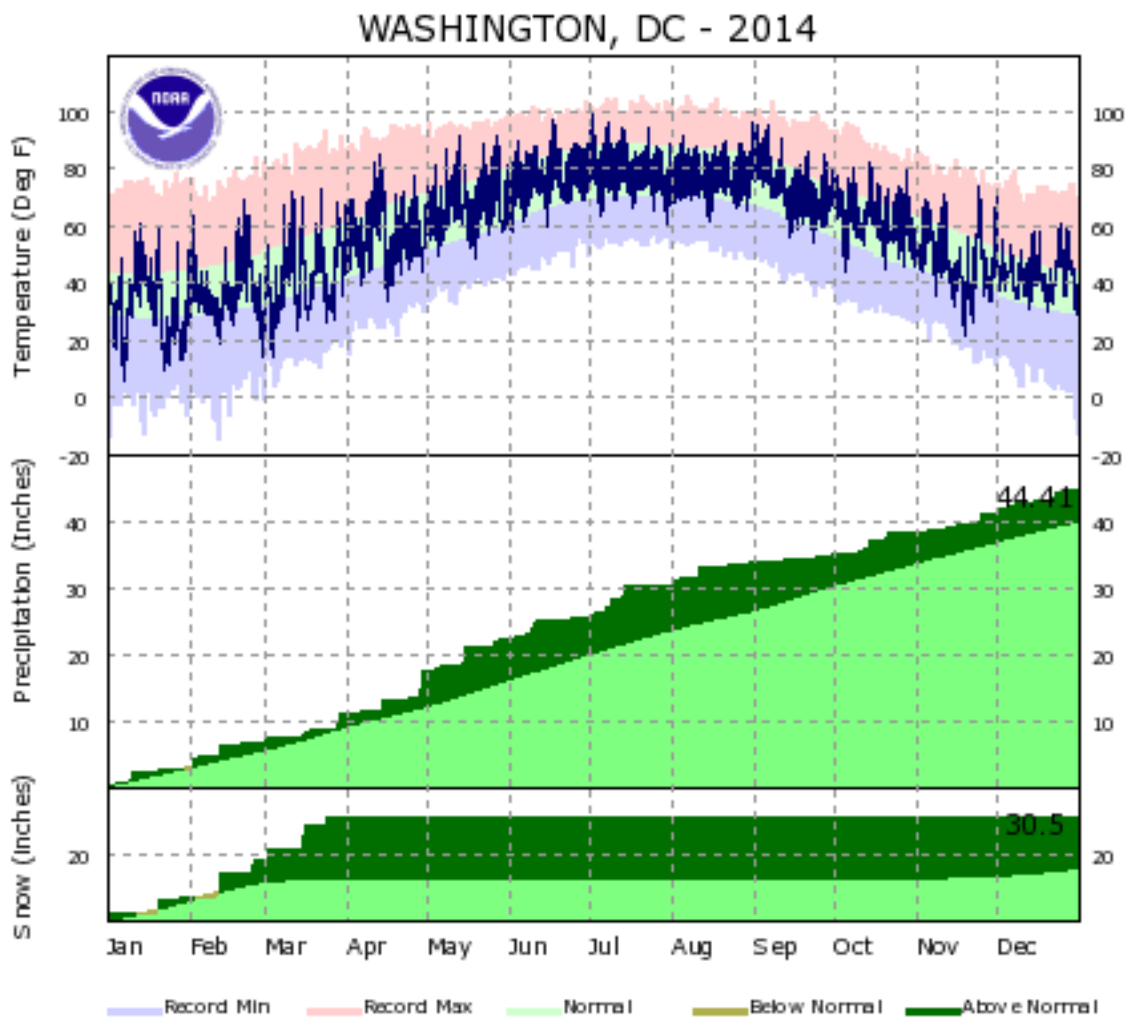
Adapted from http://www.ipod.org.uk

Real-life superposition

Temperatures (top panel), rainfall (middle panel), and snowfall (bottom panel), at DCA from Jan-Dec 2014

Note the variability across time scales: diurnal, synoptic, and seasonal

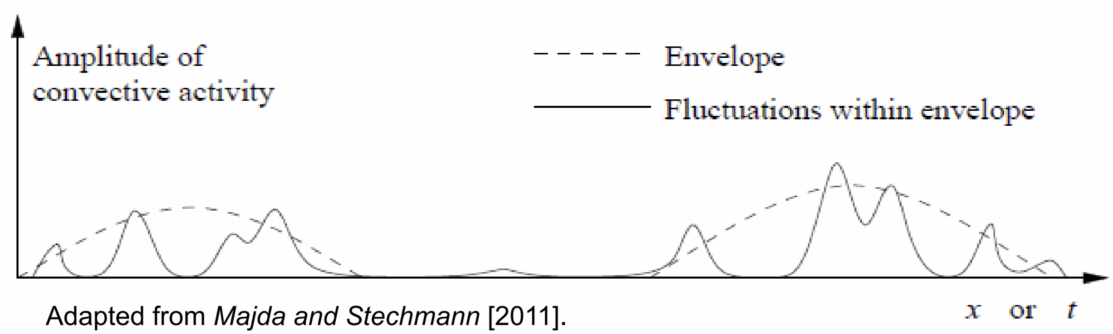
Intraseasonal (30-60 day) variability is often harder to see in extratropics (have to remove the seasonal cycle)



http://www.erh.noaa.gov/lwx/climate/cliplot/KDCA2014plot-2.png

What is the MJO?

- MJO: a quasi-periodic oscillation of the near-equatorial troposphere
  - Most noticeable in zonal winds in the boundary layer and in convection in the Eastern Hemisphere
- On the intraseasonal time scale (40-50 days), the dominant oscillation is itself a superposition of smaller features
  - But those smaller features tend to “bunch together” and persist, giving the oscillation its coherence

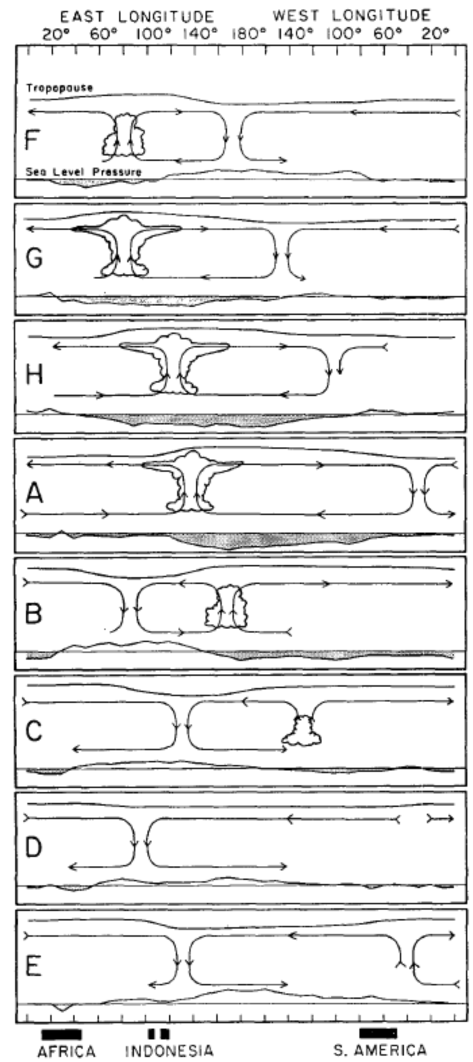


Adapted from *Majda and Stechmann* [2011].

- Discovered in late 1960s and early 1970s by Roland Madden and Paul Julian
  - Noticed regular return periods (30 to 60 days) in daily surface pressure and upper-troposphere wind observations made in the tropics

What is the MJO?

- Tropical atmospheric oscillation
  - Period of 30-60 days
- Seen as anomalous cloud clusters 2000-10000 km in horizontal scale
  - Clusters most vigorous in eastern hemisphere
  - Accompanying pressure and circulation perturbations also move east, circumnavigate planet along the equator

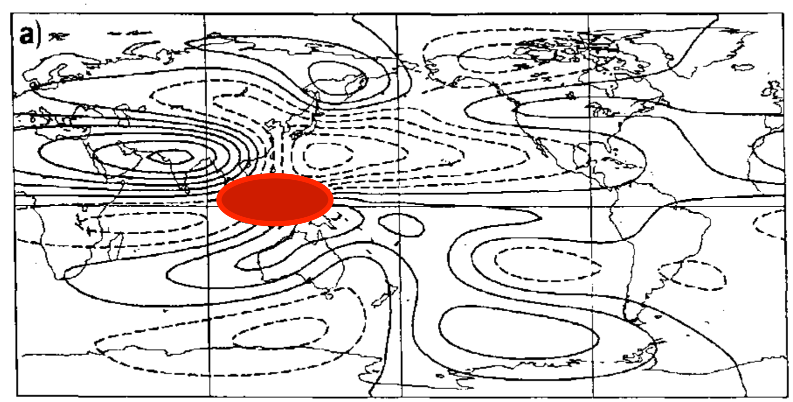


Adapted from *Madden and Julian* [1972].

Theoretical confirmation

- In mid-1980s, MJO was confirmed by numerical simulations
  - Put a heat source over Indonesia and watch how the rest of the atmosphere responds
  - Get wavy atmospheric response everywhere in upper-troposphere!
  - These waves – and their enhancement of tropical thunderstorms (akin to what Madden and Julian found) – can be split into phases

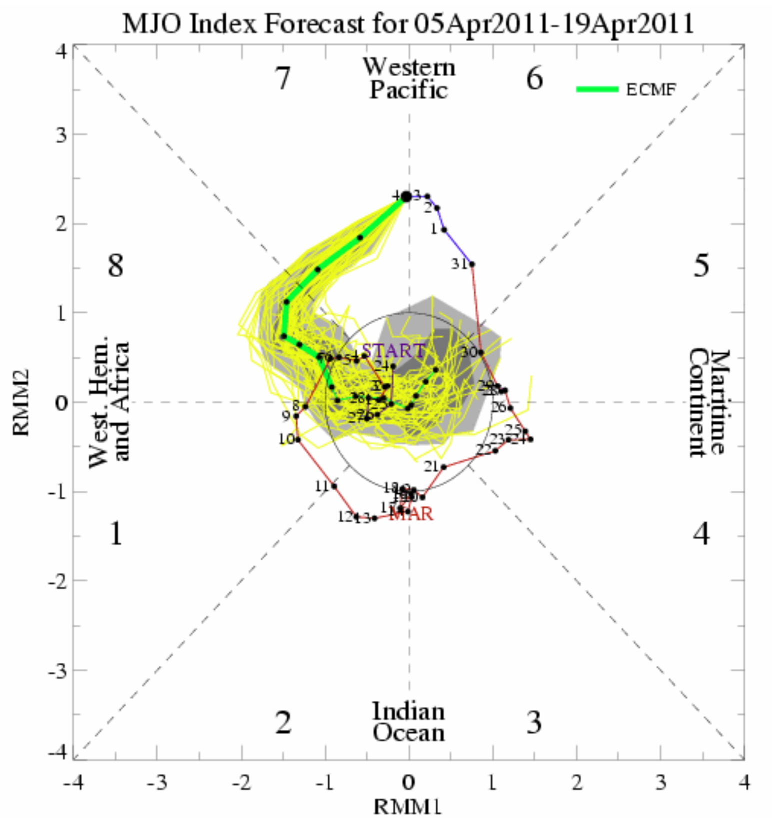
ψ anomalies



Adapted from *Sardeshmukh and Hoskins* [1988]

What is the "phase" of the MJO?

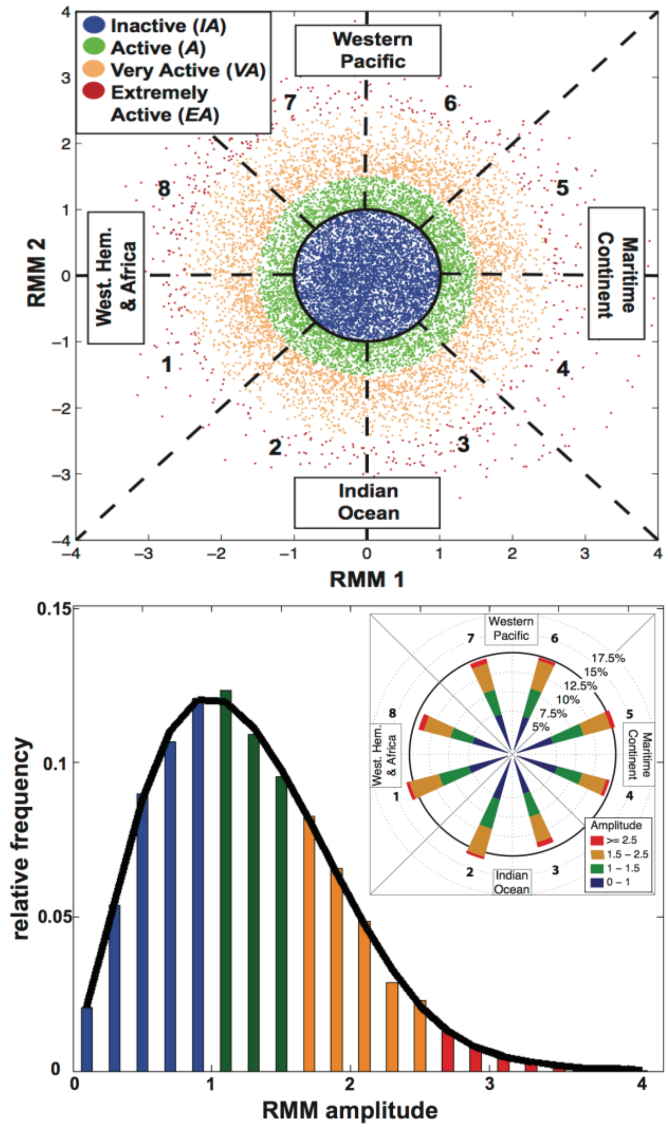
- Decomposition of the wavy MJO into two principal components that determine longitude and amplitude of the convective maximum
- MJO is starting to be predictable
  - Lots of promise for medium-range weather (or short-range climate) prediction
  - **Predictability depends on accurate data assimilation for NWP initialization**
- To take advantage of its predictability, need to understand how it affects weather around the world



Adapted from *Hendon et al.* [2011].

Character of the MJO

- Each dot (top panel) indicates daily amplitude and location of MJO 1974-2013 (over 13000 days)
- In the last 40 years:
  - 60% of days are “active”
  - 30% of days are “very active”
  - 5% of days are “extremely active”
- Peak of MJO distribution (bottom panel) occurs around amplitude of 1.0
  - Long right tail of extreme amplitudes
- Fairly equal phase distribution
  - Nearly all phases occur about 12.5% of the time



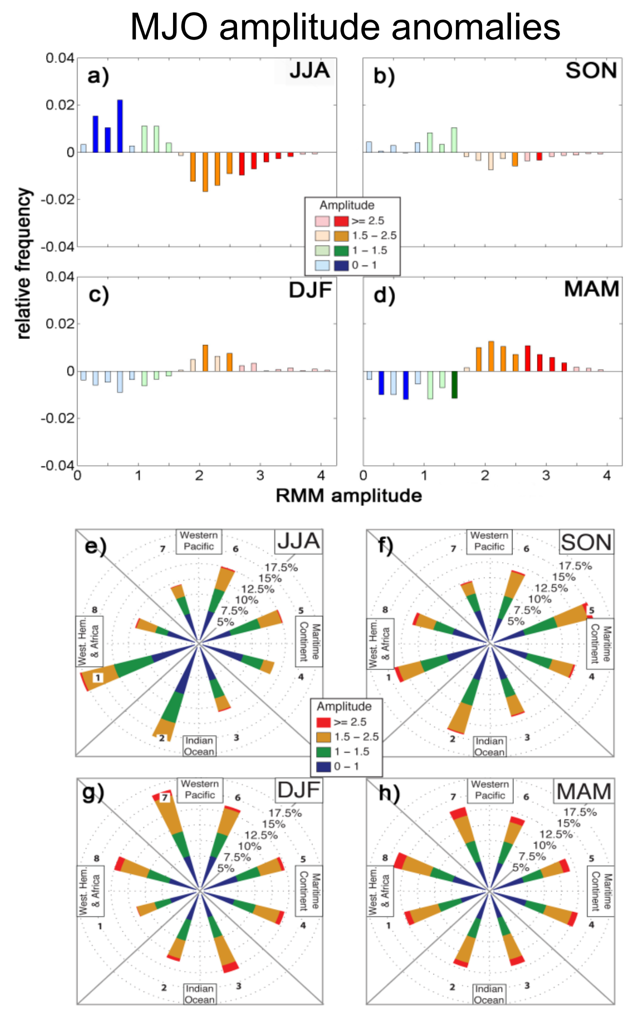
LaFleur, Barrett, and Henderson 2015 (accepted in *Journal of Climate*)

Character of the MJO

- Pronounced seasonality in MJO activity:
  - Most VA and EA days occur in DJF and MAM
  - Most IA days occur in JJA and SON

- Within a season, certain phases occur more (or less) often:
  - Phase 8 in JJA vs Phase 1 in JJA
  - Phase 1 in JJA vs Phase 1 in DJF

- What does a more amplified MJO mean?

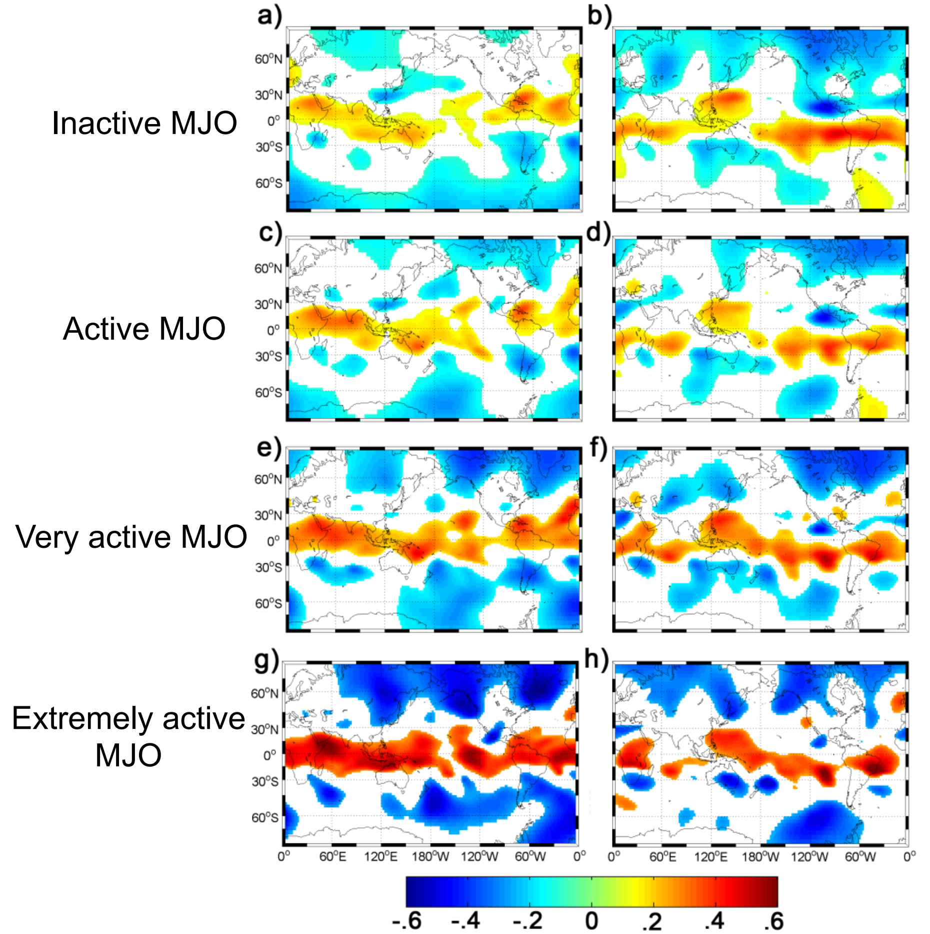


LaFleur, Barrett, and Henderson 2015 (accepted in *Journal of Climate*)

Character of the MJO

- The greater the MJO amplitude, the larger the magnitude of streamfunction anomalies at 200 hPa
  - Because streamfunction is related to non-divergent wind field, larger correlations and larger correlation gradients imply stronger zonal winds
- Implications:
  - Active MJO affects global circulation more than inactive MJO does
  - Extremely active MJO has even stronger effects

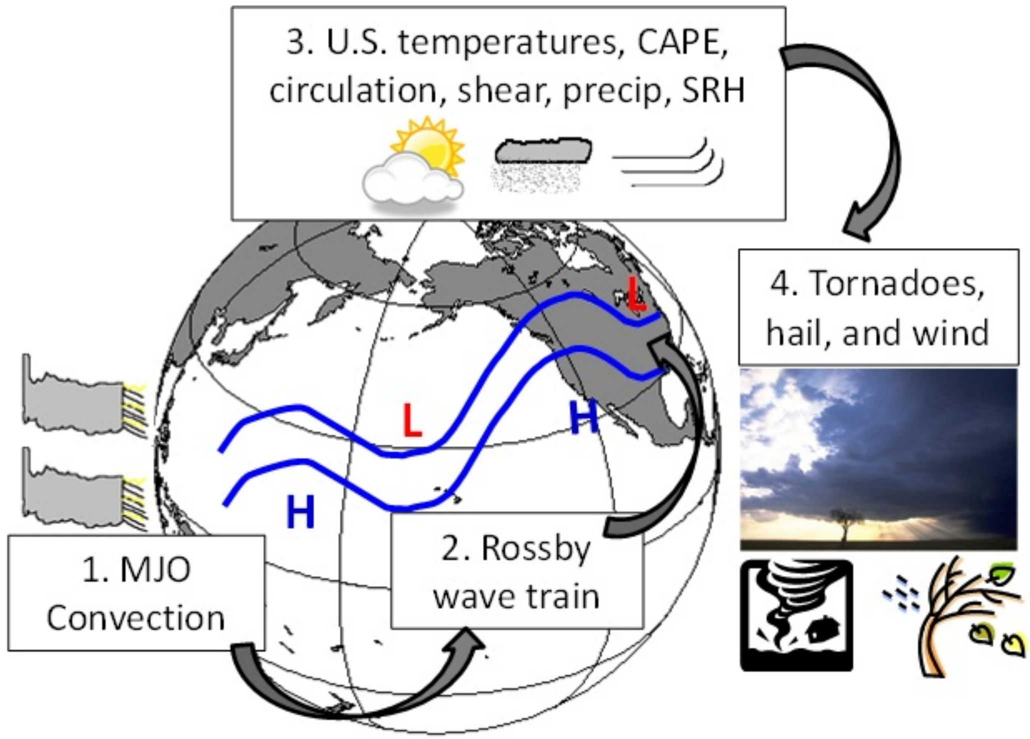
Correlation coefficient between MJO amplitude and streamfunction anomaly



LaFleur, Barrett, and Henderson 2015 (submitted to *Journal of Climate*)

Might the MJO modulate extratropical weather?

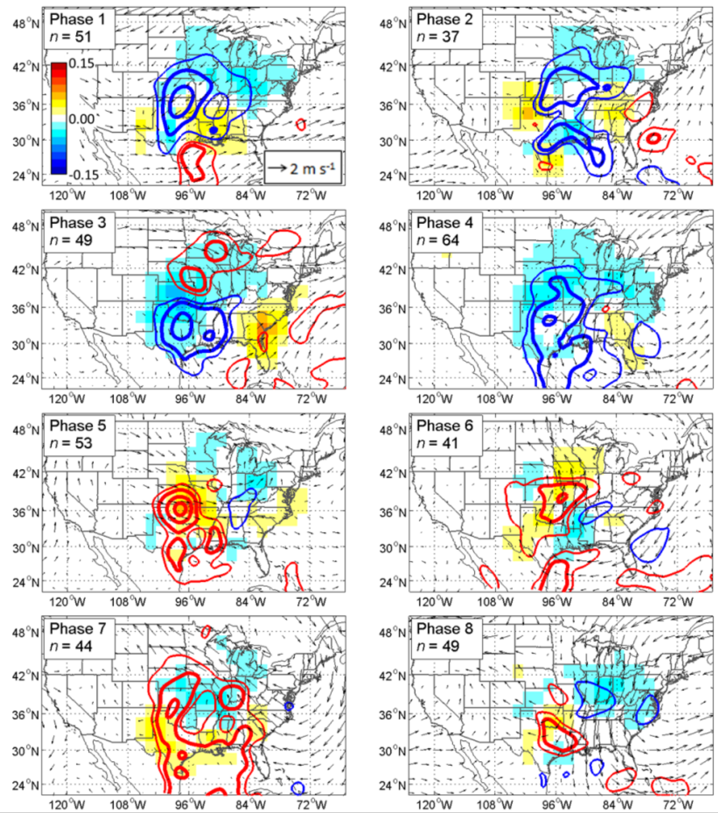
- Wavy atmospheric response to tropical MJO convective anomalies
  - Response is global: waves extend everywhere
  - Time scale for response is shorter than entire oscillation
    - 8 phases per 30-60 days gives 3-7 days per phase
    - Synoptic scale
- Hence, other weather phenomena that respond to circulations on synoptic scale could be influenced by MJO



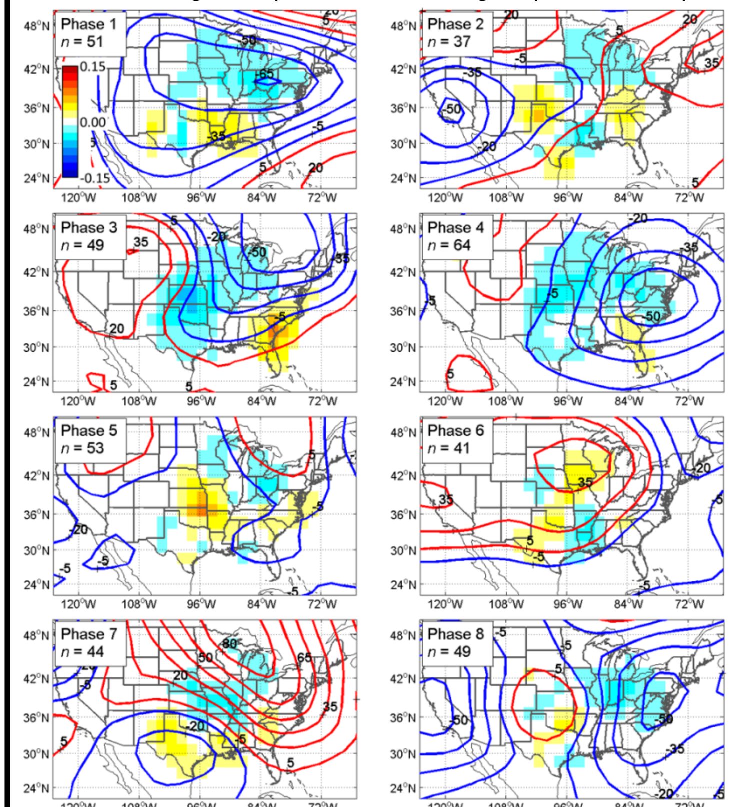
MJO and severe weather

- Notice differences in hail-day anomalies between Phases 3 and 4:
  - Below-normal hail anomalies in Phase 3
  - Above-normal anomalies in Phase 4
- Hail anomalies generally supported by buoyancy (CAPE) and circulation

April anomalies: hail-day (shaded red=positive, blue=negative); CAPE x Shear (contoured)



April anomalies: hail-day (shaded red=positive, blue=negative); 500-hPa height (contoured)



Figures from Barrett and Henley (2015 *Monthly Weather Review*)

MJO and severe weather

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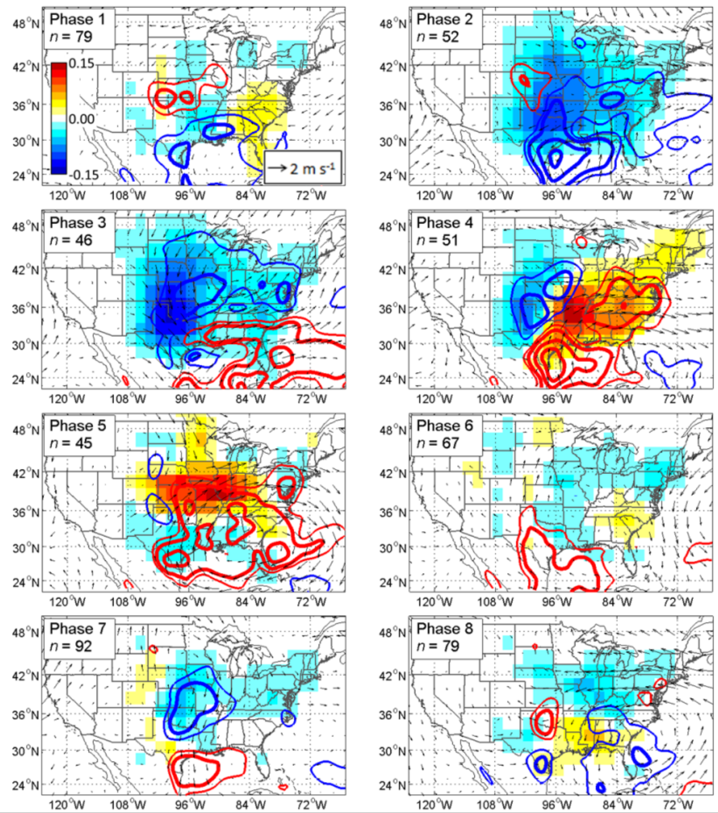

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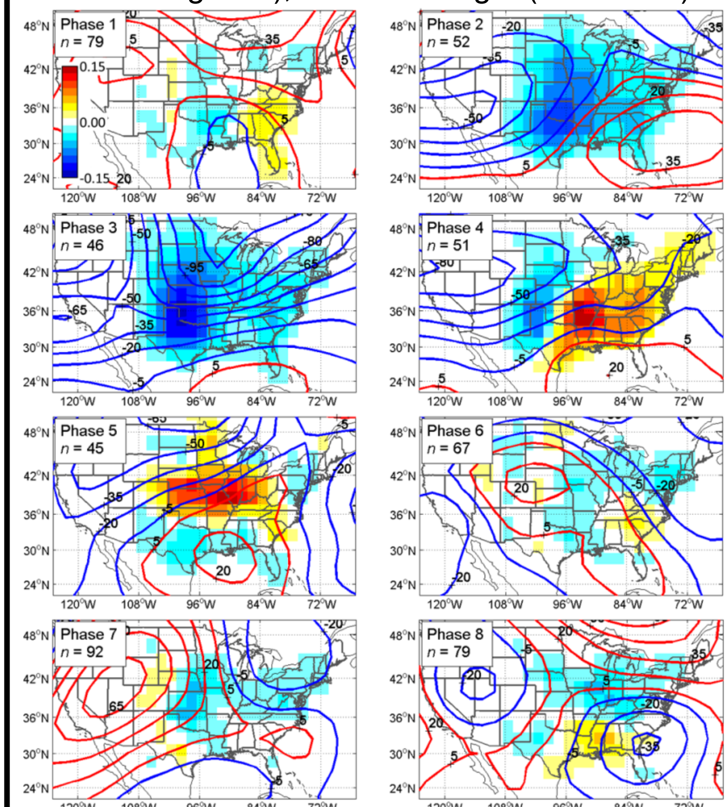
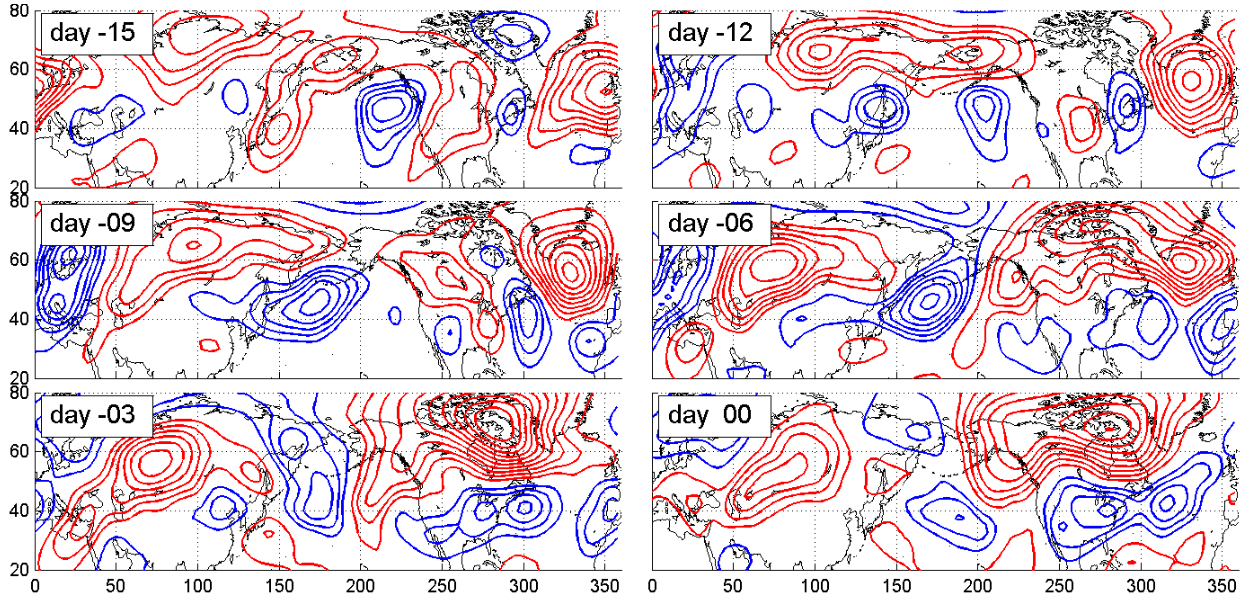


Figures from Barrett and Henley (2015 *Monthly Weather Review*)

A bit more on evolution of MJO response



Barrett and Henley (2015 *Monthly Weather Review*)

- Evolution of 200-hPa height anomalies, from 15 days to 00 days before MJO Phase 1 in April
  - Trough/ridge pattern seen over North America at day 00 largely absent 9 days prior
  - Height anomalies shift and deepen leading up to day 00
- Because MJO is cyclic, day -09 could correspond to day 00 of Phase 8

Conclusions and future work

1. MJO is a global atmospheric mode of variability
   - Leading internal mode on intraseasonal (30-60 day time scales)
2. Global circulation response to MJO heating anomalies leads to down-scale modulations of many, many weather and ocean phenomena
   - Sea ice, snow depth, hail/tornado days, air quality
3. Outstanding questions remain:
   - What lag is there between MJO convection and extratropical response
   - Does the lag even matter, given cyclic/progressive character of MJO?
   - What co-variability is there between MJO and other atmospheric modes (PNA, NAO, ENSO, etc)? E.g., does the pre-existing extratropical atmosphere matter?
   - How can the MJO be turned into something of predictive value?

Questions?

Interested in MJO-related work? Ideas? Please contact me!

Brad Barrett bbarrett@usna.edu

My strengths lie in knowing and working with observations (wind, temperature, pressure, etc.), both small (eg, point measurement) and large-scale (eg, gridded)

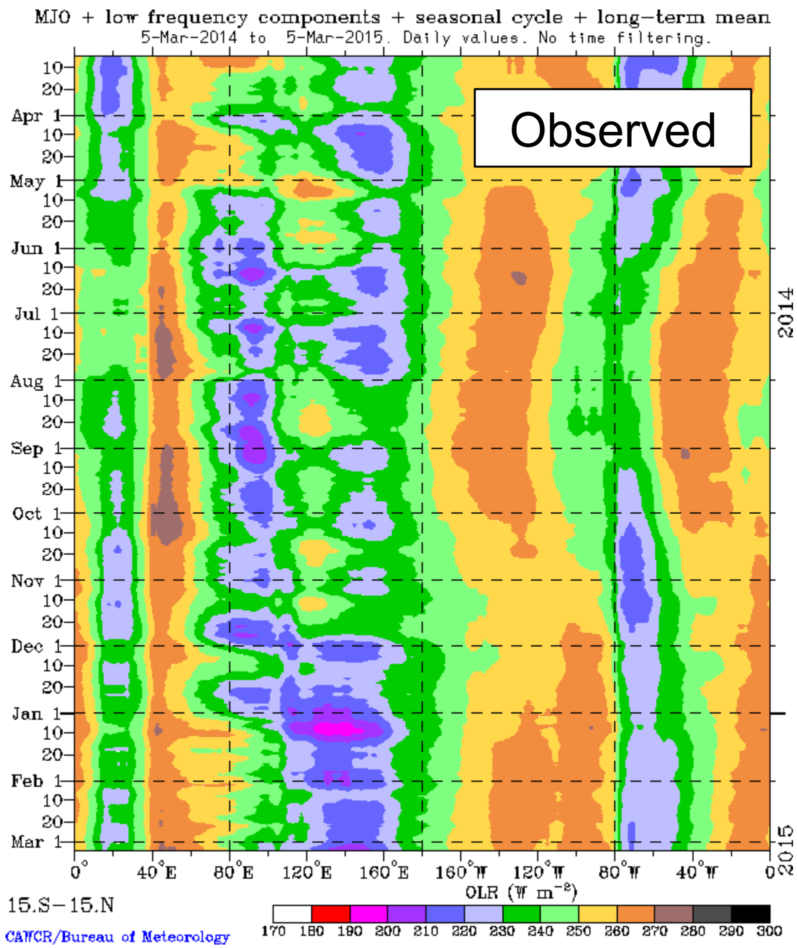
Have two NSF-funded projects. NOAA investing heavily. DOE, NASA, and ONR also

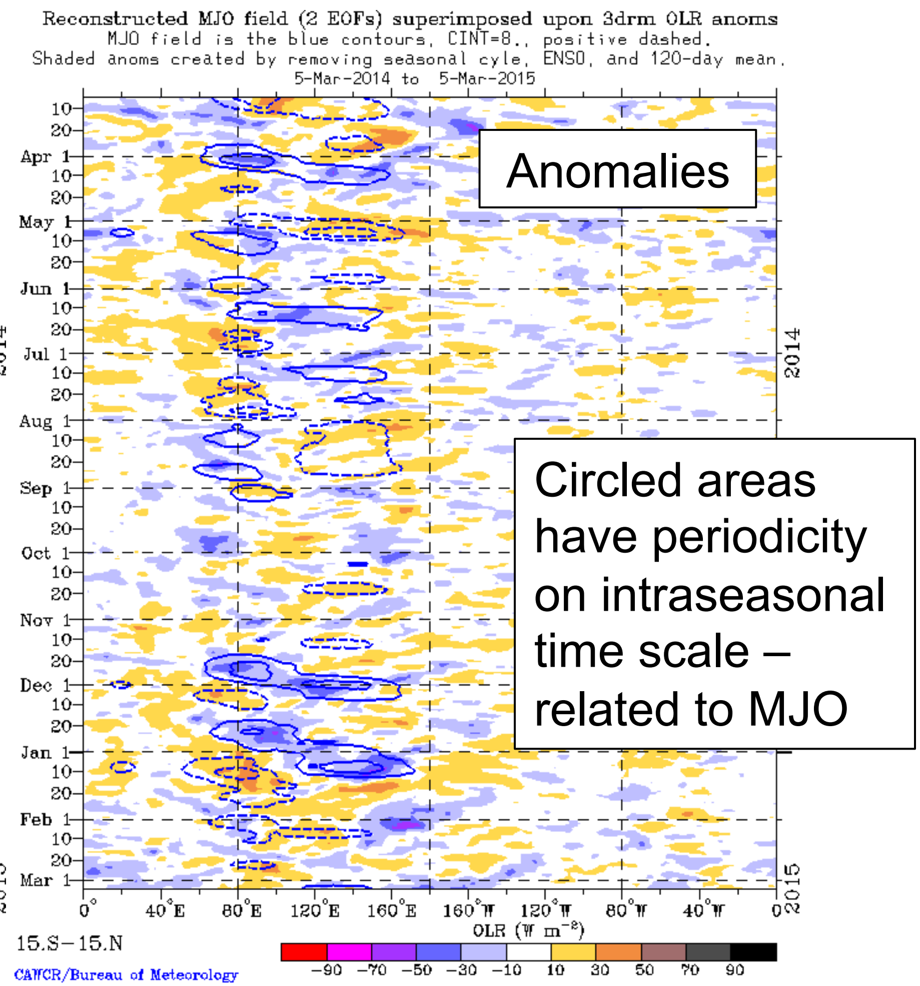
Example 1:
Removing the seasonal cycle from OLR

Equatorial outgoing long-wave radiation (OLR) from 05Mar2014 to 04Mar2015. Purple colors indicate clouds; orange colors indicate clear sky

Equatorial OLR anomalies (shading) and intraseasonal variability (blue/dashed contours)
Purple: cloudier than normal. Orange: drier than normal

Time



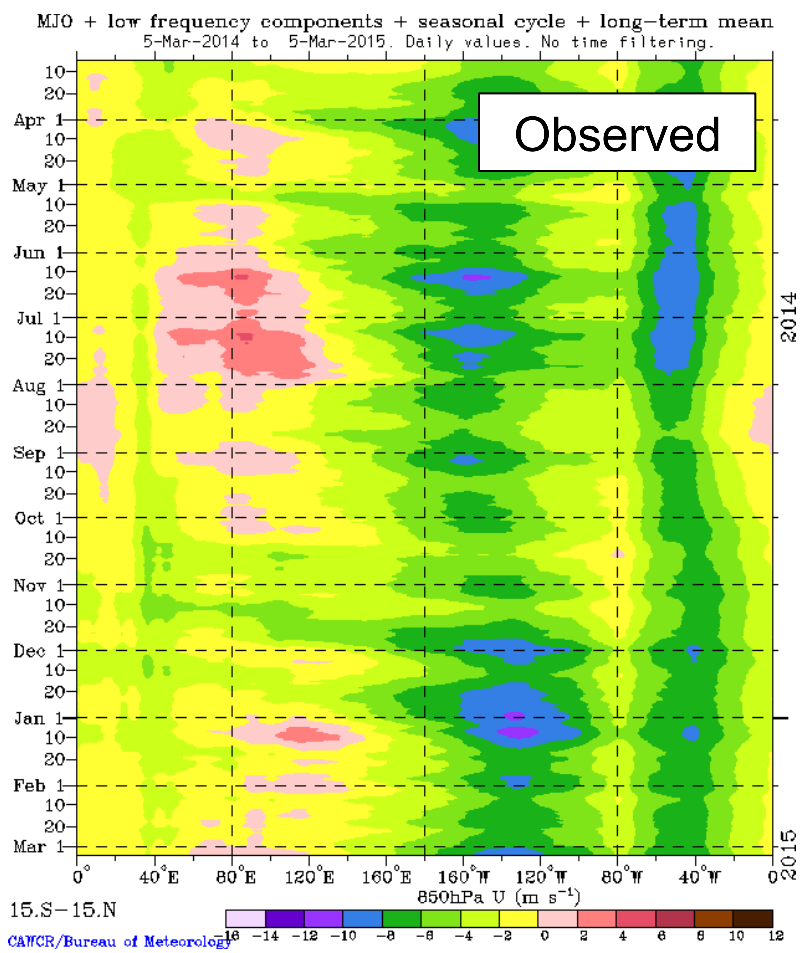


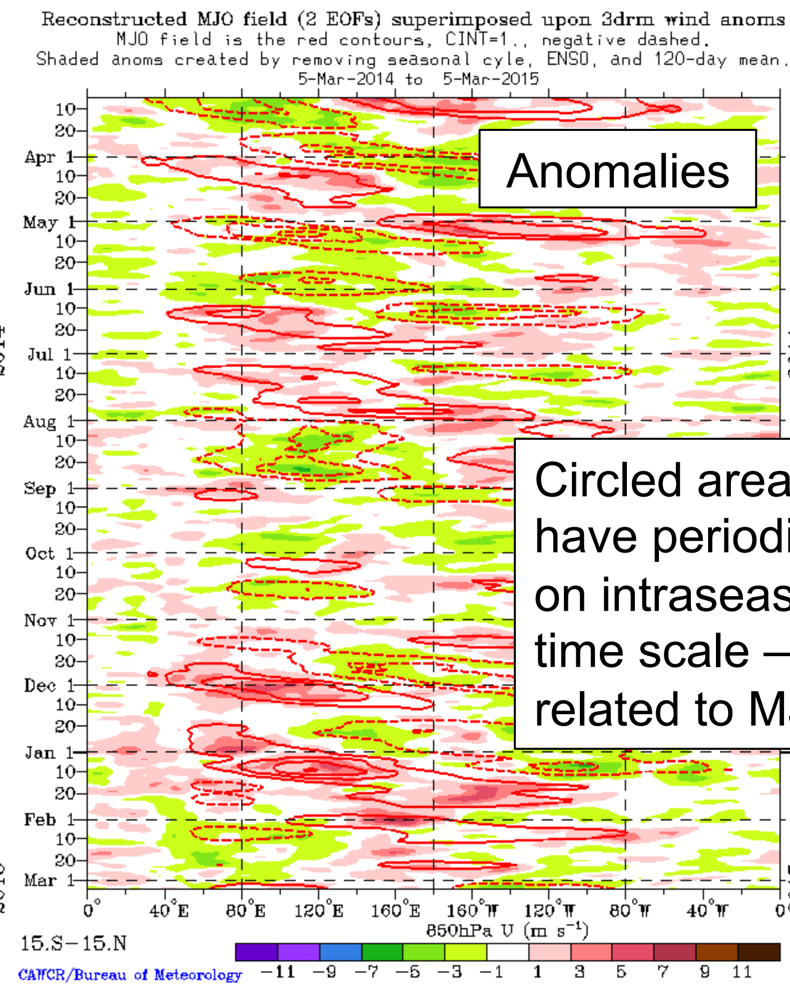
Example 2: Removing the seasonal cycle from winds

Lower-tropospheric winds (850 hPa) from 05Mar2014 to 04Mar2015. Red colors indicate winds from west; green colors indicate from east

Lower-tropospheric wind anomalies (850 hPa) from 05Mar2014 to 04Mar2015. Red colors indicate anomalies from the west; green indicates from east

Time





Circled areas have periodicity on intraseasonal time scale – related to MJO